For ZBO space transportation systems, coolers near 95 K are needed for storage of oxygen and methane. Coolers will also be required near 20 K for liquid hydrogen storage. For space applications, less complex coolers such as pulse tubes, which offer the advantage of having no moving parts at the cold head, are presently favored for these cooling requirements from an operating simplicity, reliability, and lifetime standpoint. From a versatility standpoint, 20 K coolers developed for transportation could also be used as first stages for instrument coolers that employ dilution refrigerators or adiabatic magnetization refrigerators as a second stage.

The cooler described here will be delivered to Ames in 2001 for performance testing. Then it will go to Glenn Research Center to be incorporated into a ZBO test in 2002. The ZBO test involves a partnership of three NASA centers: Ames, Glenn, and Marshall. The test will demonstrate the ZBO storage of liquid nitrogen in a 1400-liter (50-cubic-foot) tank.

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Protein Nanotechnology

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Because of NASA's efforts to make missions "faster, better, and cheaper," there is a growing need for the development of smaller, stronger, and "smarter" scientific probes compatible with space exploration. The necessary breakthroughs in this area may well be achieved in the revolutionary field of nanotechnology. This technology is on the scale of molecules, and it holds the promise of creating devices smaller and more efficient than anything currently available. While much exciting research is developing around carbon nanotube-based nanotechnology, researchers at Ames are exploring biologically inspired nanotechnology.

The biological "unit," the living cell, may be considered the ultimate nano-scale device. Cells that are constructed of nano-scale components are extremely sensitive, highly efficient environmental sensors capable of rapid self-assembly, flawless self-repair, and adaptive self improvement—not to mention their potential for nearly unlimited self-replication. Ames is focusing on a major component of all cells (proteins) that are capable of self-assembling into highly ordered structures. A protein known as HSP60, which spontaneously forms nano-scale ring structures (fig. 1a, end view; 1b, side view), that can be induced to form chains (fig. 1c) or filaments (fig. 1d), is currently being studied.

With thermostable HSP60s, highly efficient methods have been developed for purifying large quantities of these proteins; their composition and structure-forming capabilities are being currently modified by using the "tools" of molecular biology. For example, if a small fragment of the HSP60 protein is removed, protein rings are produced that do not form chains or filaments, but continue to form rings that spontaneously assemble into highly ordered hexagonally packed arrays (fig. 2a). If these proteins are modified to bind metal atoms, they can be used as a template to create an ordered pattern of metal on a surface with nanometer spacing. Ultimately the hope is to use such ordered arrays of metal to manufacture nano-scale electronic devices. Similarly,

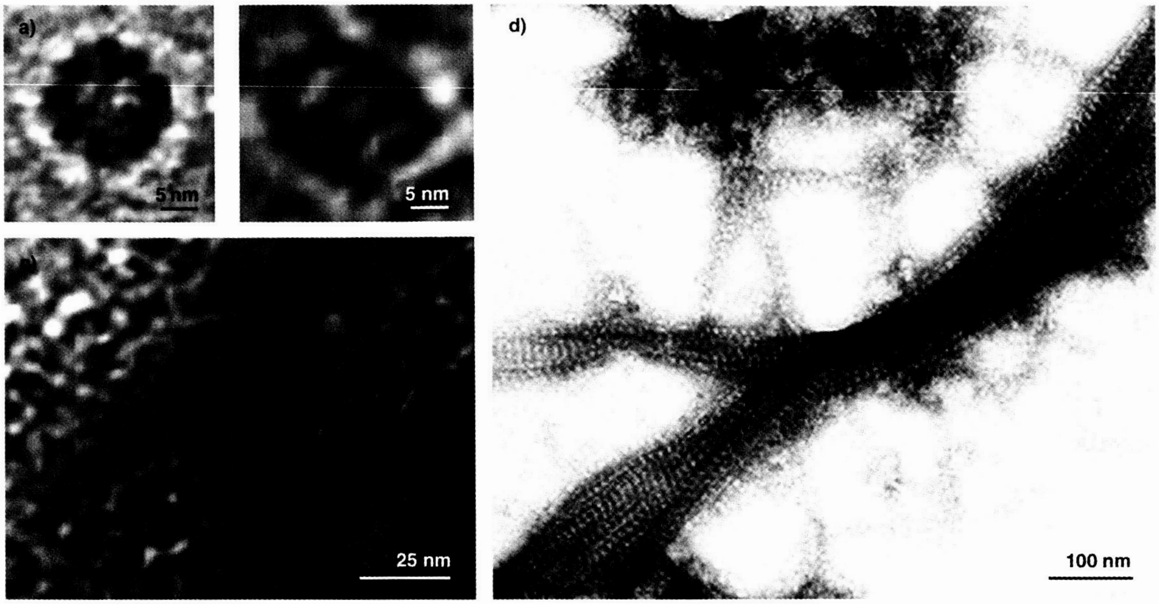

Fig. 1. Protein rings (a, end view, and b, side view), chains of rings (c), and bundles of chains (d) that can be used in nanotechnology.

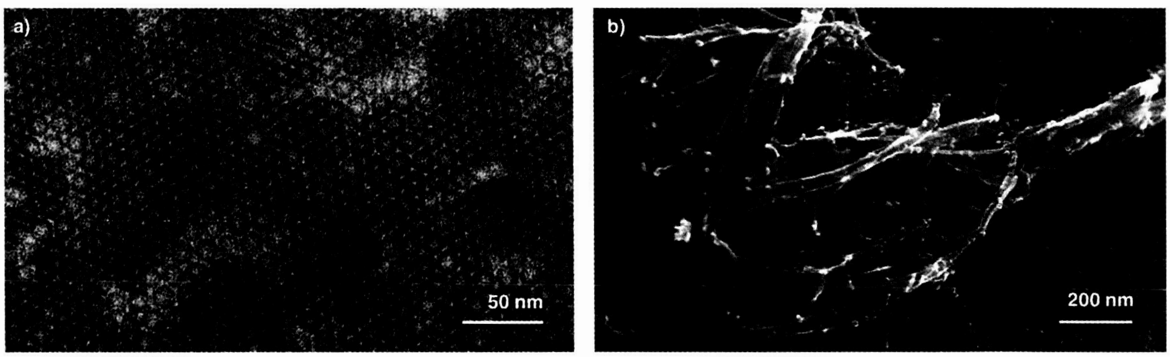

Fig. 2. Modified proteins form hexagonally packed rings (a) or metal-containing protein filaments (b).

metal binding to proteins that form filaments (fig. 2b) may be used to create self-assembling nano-scale wires, which may someday be used to produce self-assembling circuits.

Potential applications abound for protein-based nanotechnology applicable to the production of smaller, stronger, and "smarter" probes for NASA, or more generally for applications in electronics and medicine. The combination of nanotechnology, information technology, and biotechnology at Ames Research Center provides an excellent research environment for biologically inspired nanotechnology. Analytical capabilities in nanotechology provide essential tools for determining structure and function of protein-based systems. Supercomputing in information sciences provides capabilities essential for molecular simulations and biomolecule visualizations. Biotechnology provides the methodological basis for the genetic engineering essential for modifying and functionalizing protein structures. The goal is to establish the feasibility of creating useful protein-based nanostructures with applications for NASA and other critical areas of technology.

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